

ficient or irregular water supply, the soils can also undergo alternate drying and rewetting during rice growth. In some irrigated rice ecosystems with good water control in China, farmers drain rice fields during the vegetative growth phase. This midseason drainage and short-term drying of the submerged soil can control excessive tillering of rice, help regulate leaf area of rice at desired levels, and improve root activity. The midseason drainage can, however, also influence N transformations and N loss processes.

### Nitrogen Transformations

The forms of N present in submerged soils are generally similar to those in aerated soils; but the relative magnitude of the N forms, particularly nitrate ( $\text{NO}_3^-$ ) and ammonium ( $\text{NH}_4^+$ ), and N transformation are markedly affected by the oxidation status of soil (Fig. 11-1). Nitrate is the dominant form of inorganic N in drained, aerated soils; whereas  $\text{NH}_4^+$  is the dominant and stable form of inorganic N that accumulates in submerged soils. When  $\text{O}_2$  is present, such as in aerated soils and in the localized aerobic zone of submerged soils,  $\text{NH}_4^+$  is converted to  $\text{NO}_3^-$ . This  $\text{NO}_3^-$  is not readily denitrified (reduced) in the aerated soil, and it can consequently accumulate. In the anaerobic zone of submerged soils, which constitutes the vast proportion of a submerged soil,  $\text{NH}_4^+$  is not converted to  $\text{NO}_3^-$ . Nitrate moving into the anaerobic zone or residing in the soil before submergence and depletion of  $\text{O}_2$  can be readily denitrified.

Nitrogen is typically the main limiting nutrient in the production of lowland rice, and use of N fertilizer is vital for the sustained production of sufficient rice to meet demand. About 20% of the global production of fertilizer N is used in rice production systems that experience soil submergence (Dat Tran, personal communication, 2001). Yet the use efficiency of this fertilizer N by the crop is typically low, due at least in part to losses of the applied fertilizer N arising from unique features of submerged soils as compared with aerated soils.

The main N transformation processes in submerged soils—as in aerated soils—are mineralization, immobilization, nitrification, denitrification, ammonia ( $\text{NH}_3$ ) volatilization, and biological  $\text{N}_2$  fixation. Soil submergence modifies these processes, and a unique feature of submerged soils is the simultaneous formation and loss of  $\text{NO}_3^-$ , occurring within the adjoining aerobic and anaerobic soil zones. Submerged soils as compared with aerated soils are favorable environments for loss of N by nitrification–denitrification,  $\text{NH}_3$  volatilization, and for addition of N via biological  $\text{N}_2$  fixation (BNF).

### Mineralization and Immobilization

Mineralization, or more specifically ammonification—the conversion of soil organic N to ammonium—supplies plant-available N in submerged agricultural soils. Even with high-yielding rice crops receiving high rates of fertilizer N, >50% of the total N assimilated by the crop typically originates from the breakdown of soil organic N compounds (Mikkelsen, 1987; Cassman et al., 1998). This breakdown of organic N in submerged soils is characterized by anaerobic decomposition, which involves different microorganisms and endproducts than aerobic decomposition. Ammonium accumulates in anaerobic decomposition due to the absence of  $\text{O}_2$ , which is required for conversion of  $\text{NH}_4^+$  to  $\text{NO}_3^-$ .